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(54) **PERPENDICULAR RECORDING MEDIA WITH GRAIN ISOLATION INITIATION LAYER AND EXCHANGE BREAKING LAYER FOR SIGNAL-TO-NOISE RATIO ENHANCEMENT**

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G11B 5/84	(2006.01)
G11B 5/65	(2006.01)
G11B 5/73	(2006.01)

(52) **U.S. Cl.**
CPC .. ***G11B 5/84*** (2013.01); ***G11B 5/65*** (2013.01); ***G11B 5/66*** (2013.01); ***G11B 5/7325*** (2013.01); *Y10T 29/49021* (2015.01)

(58) **Field of Classification Search**
CPC G11B 5/746; G11B 5/59688; G11B 5/855
USPC 428/829–831
See application file for complete search history.

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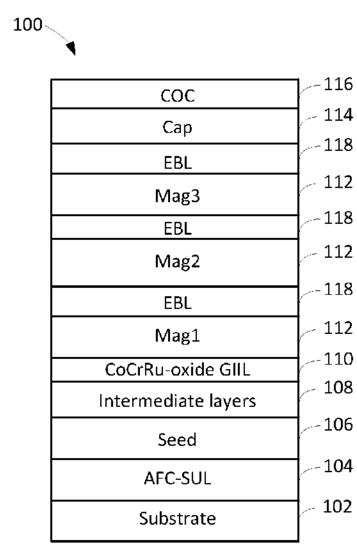
(57) **ABSTRACT**

Aspects of the present invention relate to a perpendicular magnetic recording (PMR) media stack and methods for fabricating the same. The PMR media stack has a novel grain isolation initiation layer (GIIL) and/or a novel exchange-break layer (EBL) that can improve the signal-to-noise performance of the PMR media stack. The PMR media stack includes a substrate, a soft underlayer on the substrate, an interlayer positioned on the soft underlayer, and a grain isolation initiation layer (GIIL) positioned on the interlayer, a magnetic layer positioned on the GIIL, and an exchange break layer (EBL) positioned on the magnetic layer. The GIIL and/or EBL includes a CoCrRu-oxide.

18 Claims, 8 Drawing Sheets



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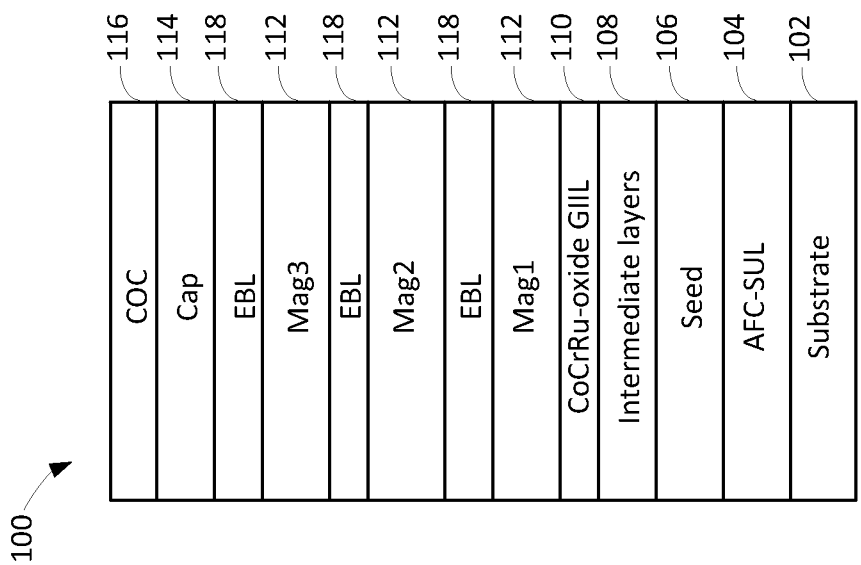
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116
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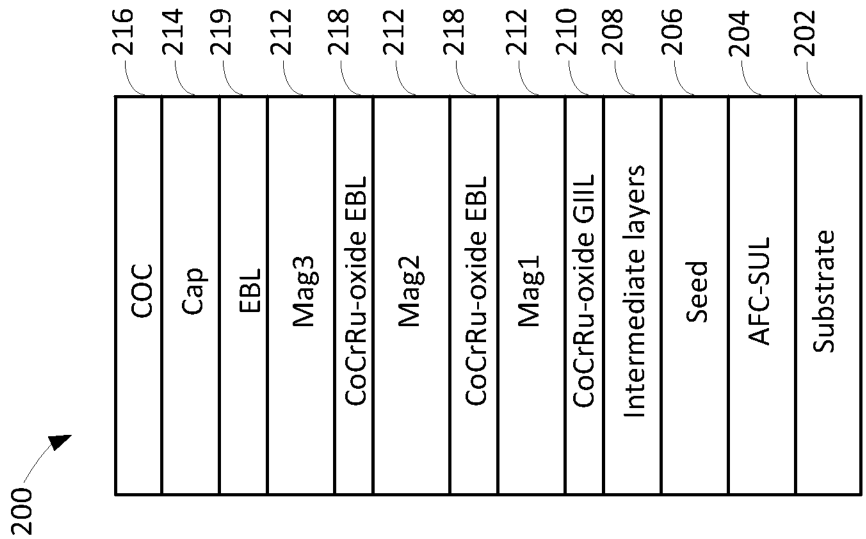
104
102
COC
Cap
EBL
Mag3
EBL
Mag2
EBL
Mag1
CoCrRu-oxide GIIL
Intermediate layers
Seed
AFC-SUL
Substrate

FIG. 1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214
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212
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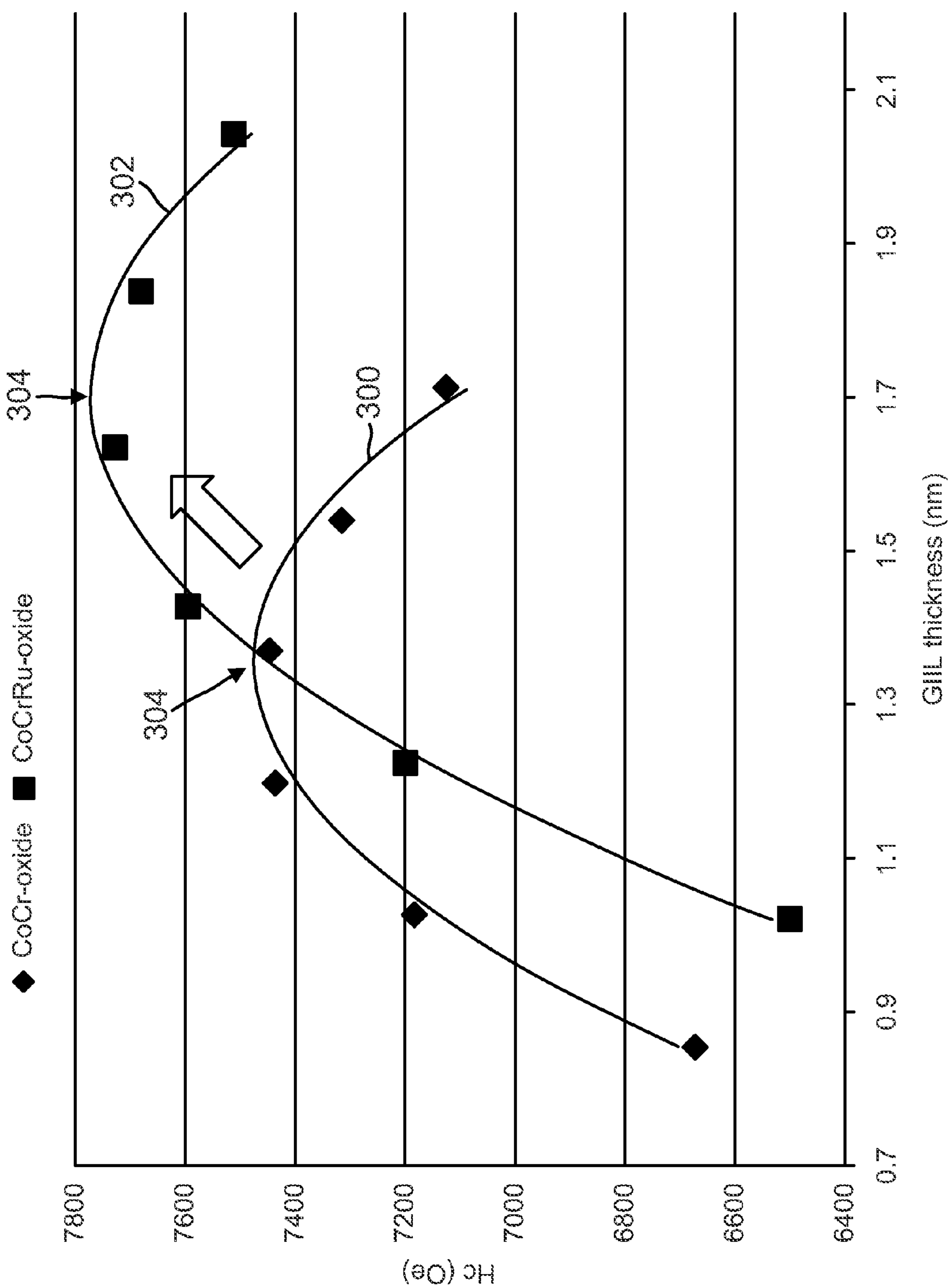
212
218
212
210
208
206
204
202
COC
Cap
EBL
Mag3
CoCrRu-oxide EBL
Mag2
CoCrRu-oxide EBL
Mag1
CoCrRu-oxide GIIL
Intermediate layers
Seed
AFC-SUL
Substrate

FIG. 2



CoCr-oxide
CoCrRu-oxide
Hc (Oe)
7800
7600
7400
7200
7000
6800
6600
6400
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
GIIL thickness (nm)
300
302
304
304

FIG. 3

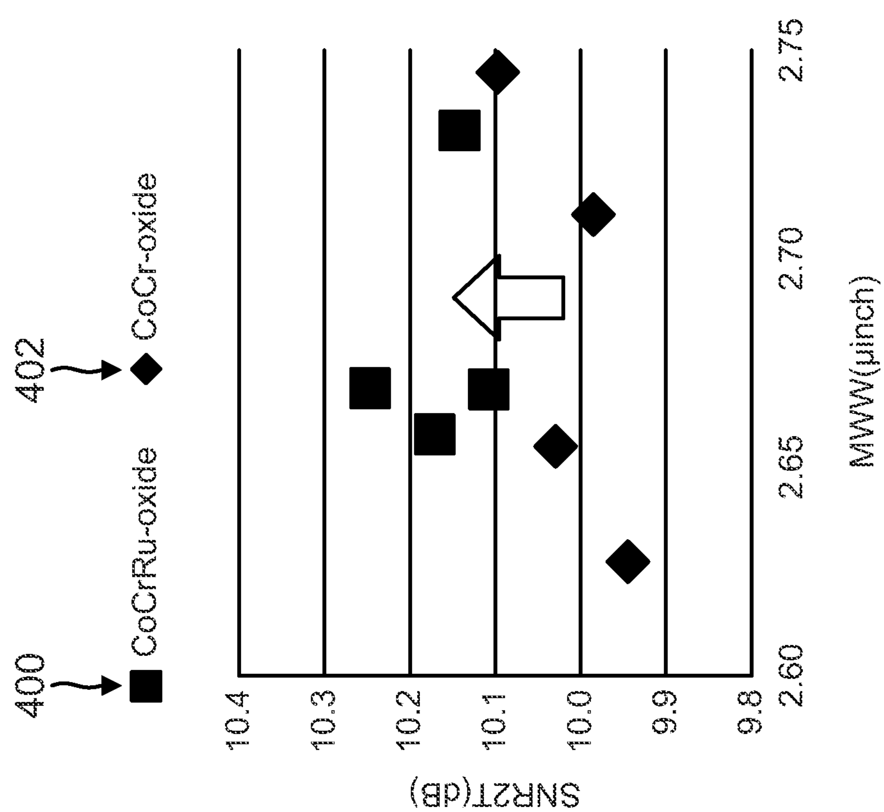

400
402
CoCrRu-oxide
CoCr-oxide
SNR2T(dB)
10.4
10.3
10.2
10.1
10.0
9.9
9.8
2.60
2.65
2.70
2.75
MWW(µinch)

FIG. 4

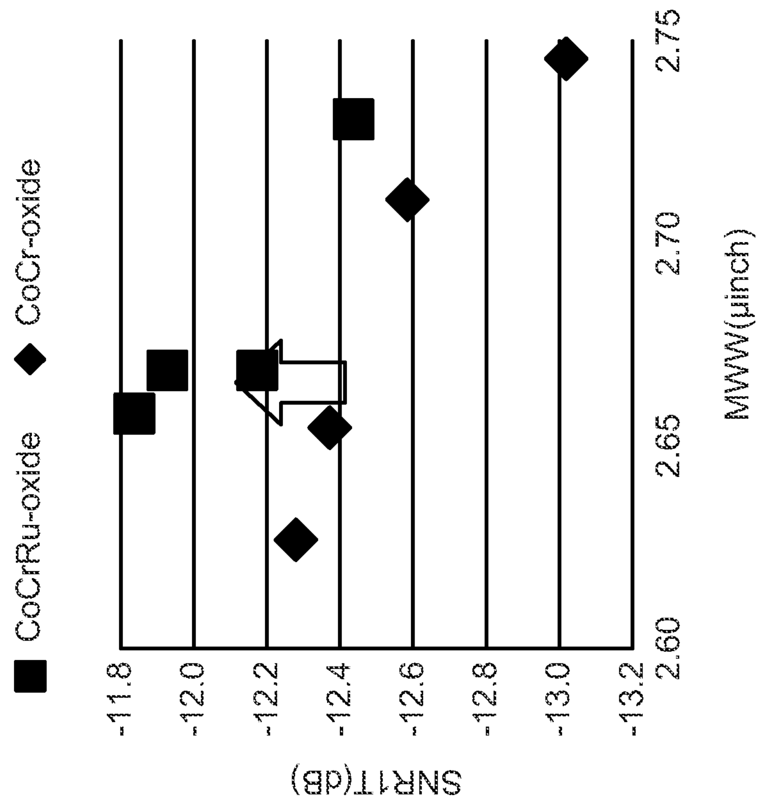

CoCrRu-oxide
CoCr-oxide
SNR1T(dB)
-11.8
-12.0
-12.2
-12.4
-12.6
-12.8
-13.0
-13.2
2.60
2.65
2.70
2.75
MWW(µinch)

FIG. 5

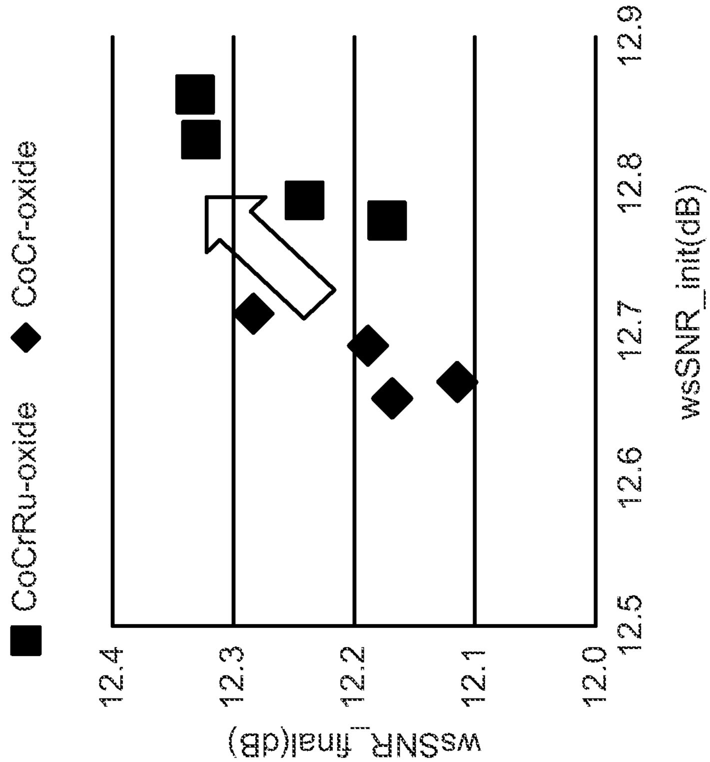

CoCrRu-oxide
CoCr-oxide
wsSNR_final(dB)
12.4
12.3
12.2
12.1
12.0
wsSNR_init(dB)
12.5
12.6
12.7
12.8
12.9

FIG. 7

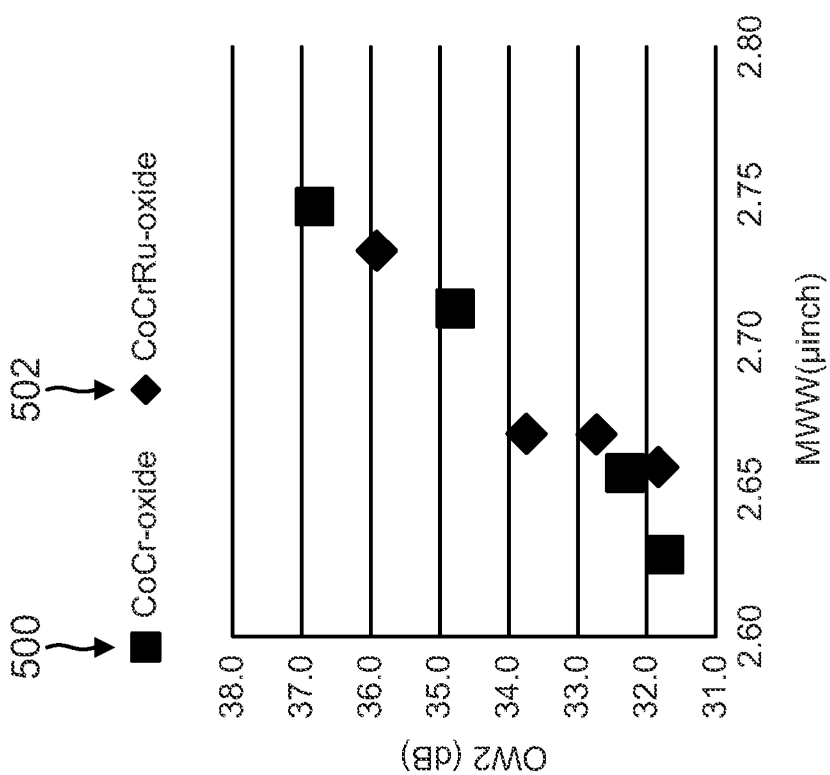

500
CoCr-oxide
502
CoCrRu-oxide
OW2 (dB)
38.0
37.0
36.0
35.0
34.0
33.0
32.0
31.0
MWW(µinch)
2.60
2.65
2.70
2.75
2.80

FIG. 6

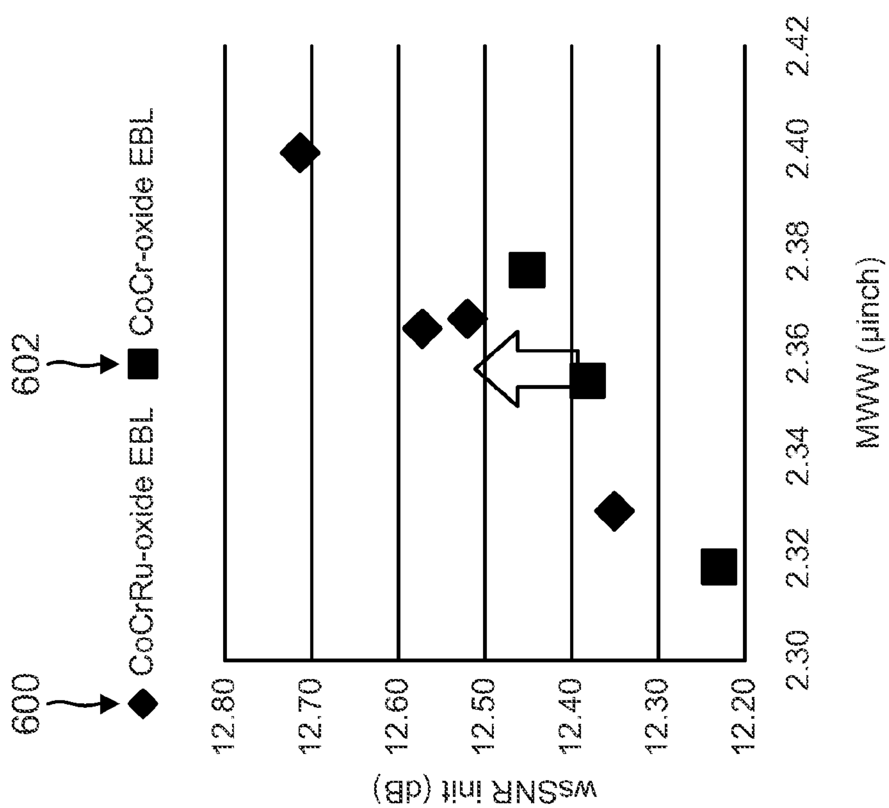

600
602
CoCrRu-oxide EBL
CoCr-oxide EBL
wsSNR init (dB)
12.80
12.70
12.60
12.50
12.40
12.30
12.20
2.30
2.32
2.34
2.36
2.38
2.40
2.42
MWW (µinch)

FIG. 8

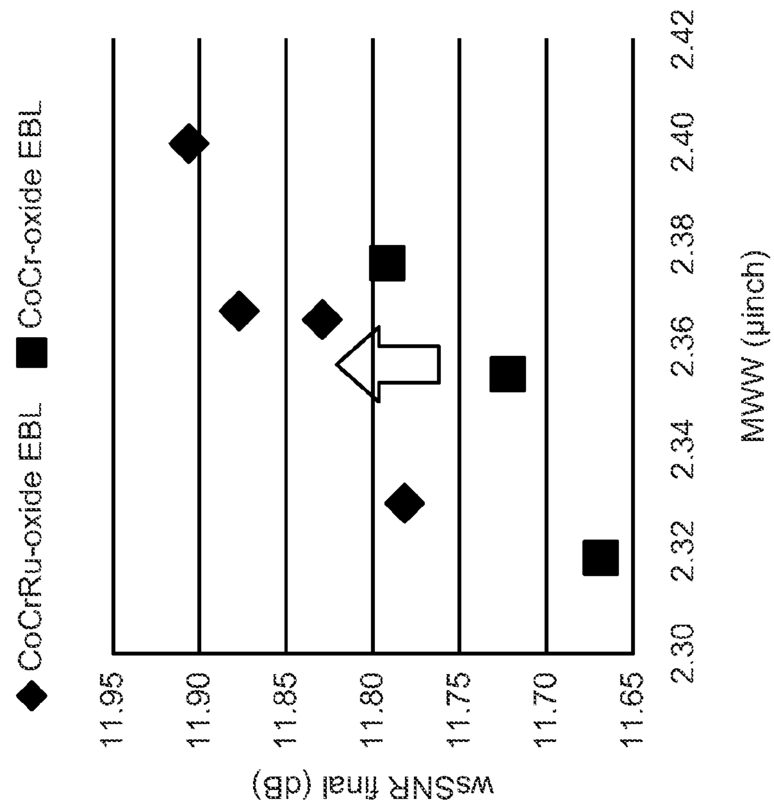

CoCrRu-oxide EBL
CoCr-oxide EBL
wsSNR final (dB)
11.95
11.90
11.85
11.80
11.75
11.70
11.65
2.30
2.32
2.34
2.36
2.38
2.40
2.42
MWW (µinch)

FIG. 9

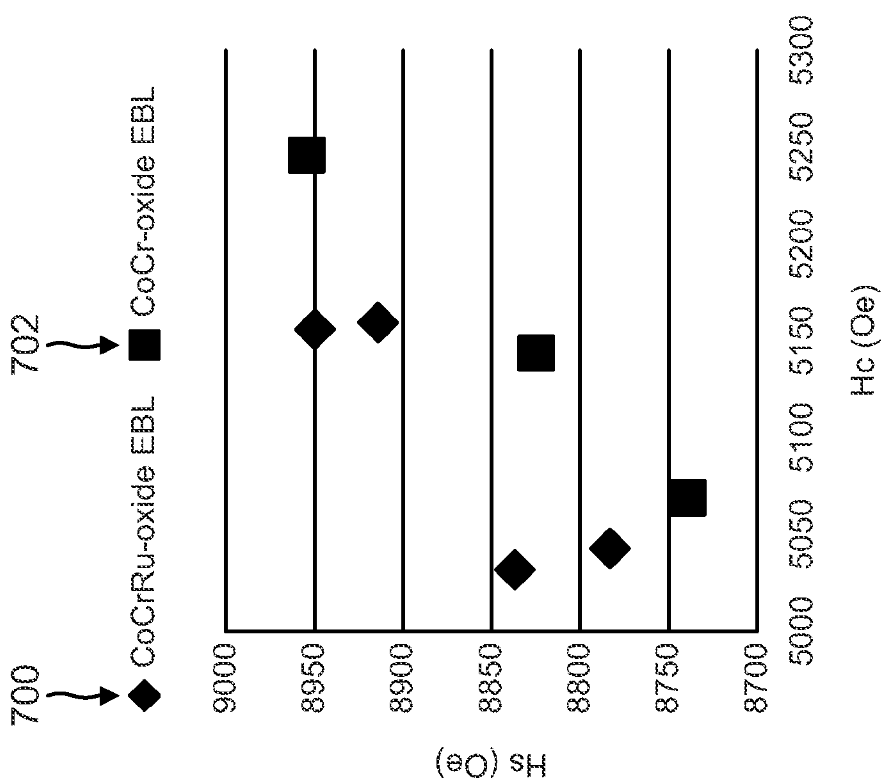

700
702
CoCrRu-oxide EBL
CoCr-oxide EBL
Hs (Oe)
9000
8950
8900
8850
8800
8750
8700
Hc (Oe)
5000
5050
5100
5150
5200
5250
5300

FIG. 10

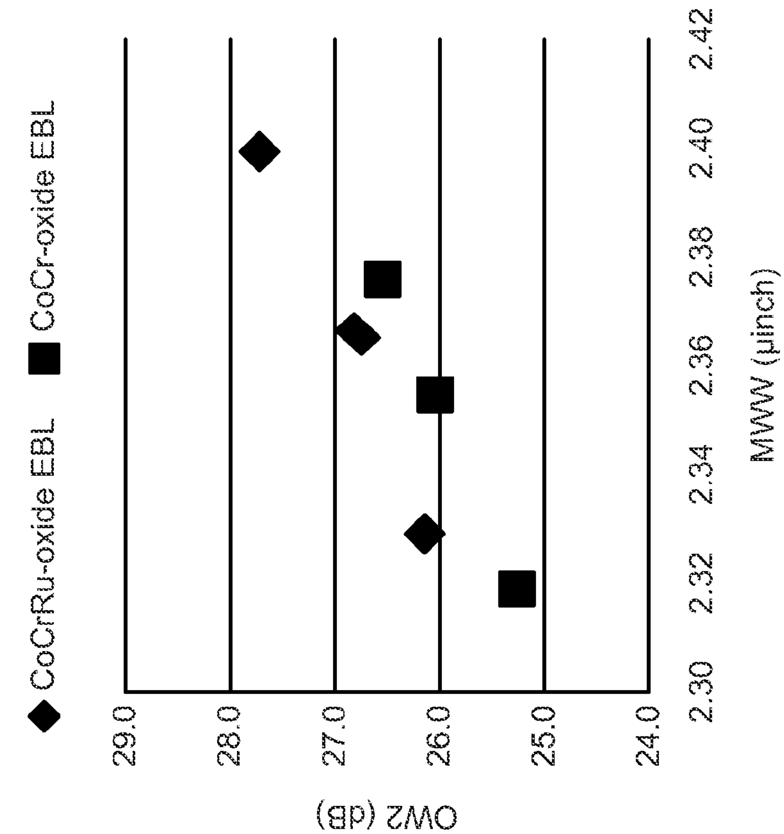

CoCrRu-oxide EBL
CoCr-oxide EBL
OW2 (dB)
29.0
28.0
27.0
26.0
25.0
24.0
MWW (μinch)
2.30
2.32
2.34
2.36
2.38
2.40
2.42

FIG. 11

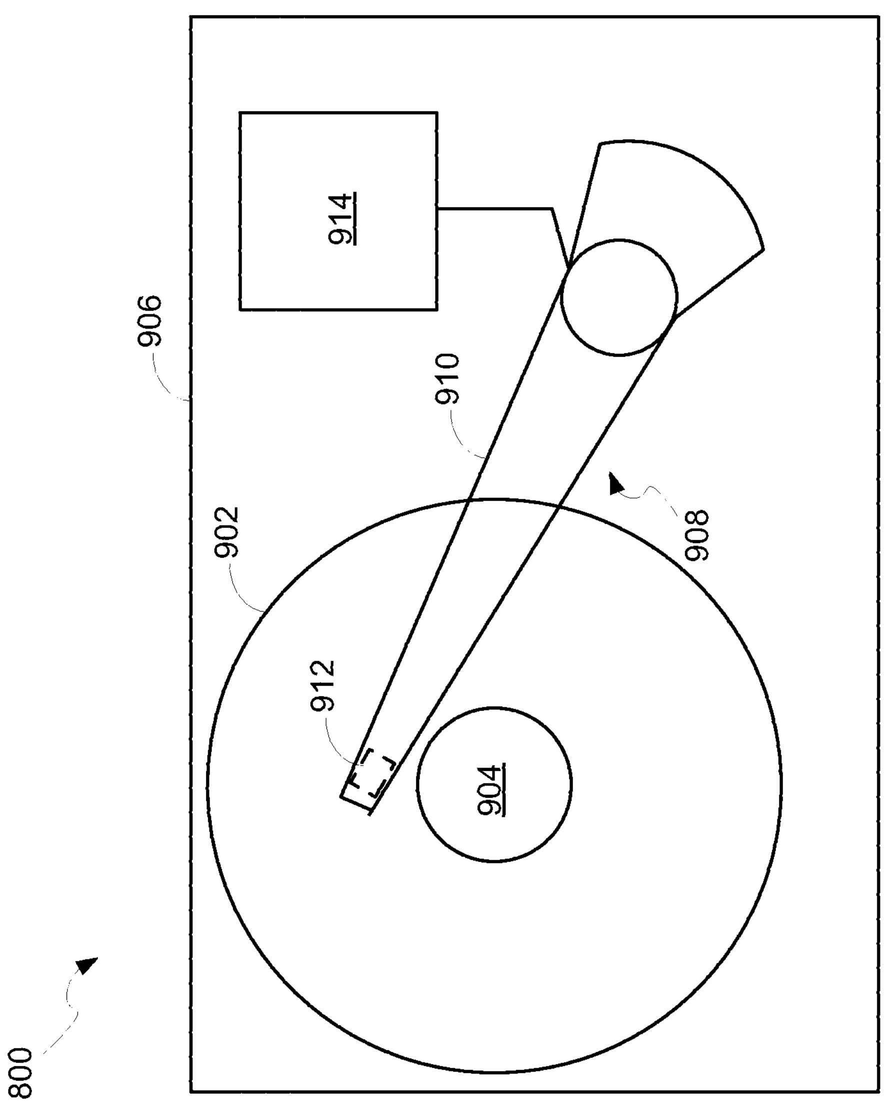


FIG. 12

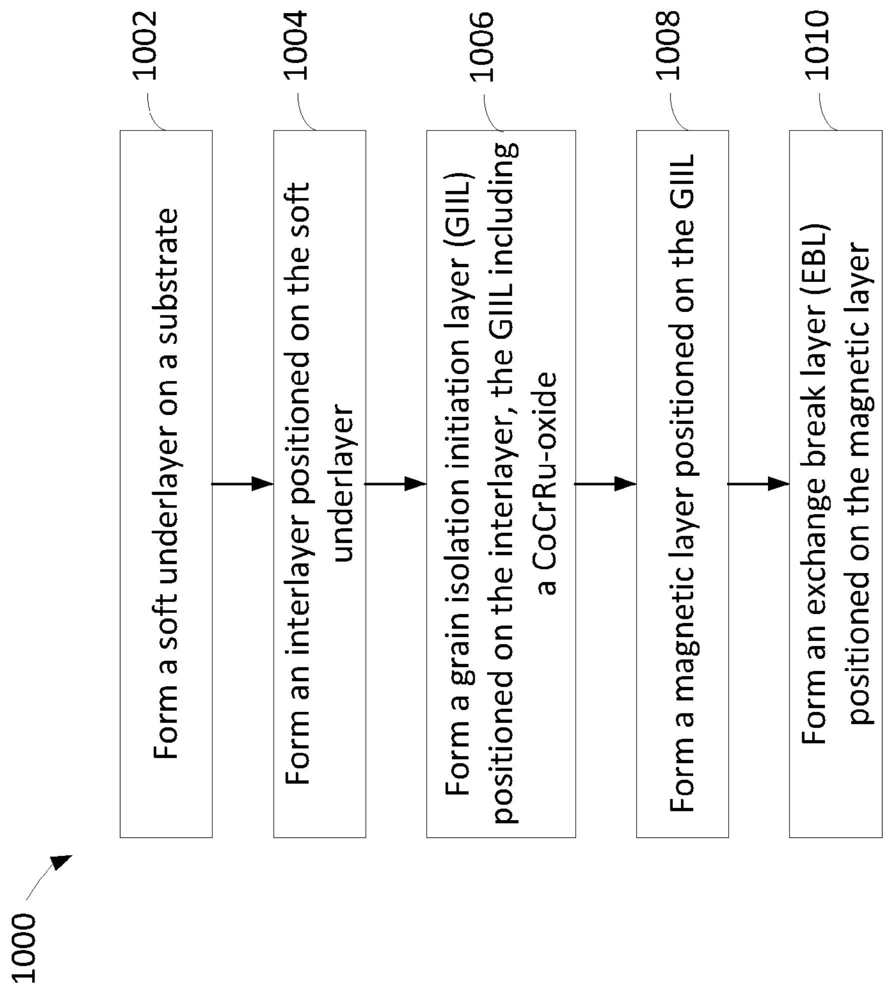

1000
1002
Form a soft underlayer on a substrate
1004
Form an interlayer positioned on the soft underlayer
1006
Form a grain isolation initiation layer (GIIL) positioned on the interlayer, the GIIL including a CoCrRu-oxide
1008
Form a magnetic layer positioned on the GIIL
1010
Form an exchange break layer (EBL) positioned on the magnetic layer

FIG. 13

PERPENDICULAR RECORDING MEDIA WITH GRAIN ISOLATION INITIATION LAYER AND EXCHANGE BREAKING LAYER FOR SIGNAL-TO-NOISE RATIO ENHANCEMENT

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims priority to and the benefit of U.S. Provisional Application No. 61/808,561 filed on Apr. 4, 2013, entitled "PERPENDICULAR RECORDING MEDIA WITH NEW GRAIN ISOLATION INITIATION LAYER AND/OR EXCHANGE BREAKING LAYER FOR SIGNAL TO NOISE RATIO ENHANCEMENT", the entire content of which is incorporated herein by reference.

FIELD

Aspects of the present invention relate to magnetic recording media, and more specifically to grain isolation initiation layer and exchange breaking layer of perpendicular magnetic recording (PMR) media.

BACKGROUND

Perpendicular magnetic recording (PMR) has been used to increase the areal recording density of magnetic storage media. A PMR media stack generally includes a substrate, an antiferromagnetic coupled soft magnetic underlayer (AFC-SUL), a seed layer, an intermediate layer, a grain isolation initiation layer (GIIL) and a magnetic layer stack, in that order. The magnetic layer stack includes a number of magnetic layers separated by a number of exchange-break layers (EBLs) or exchange-control layers (ECLs). The GIIL can enhance magnetic decoupling of the magnetic layers, and the EBLs help to reduce the coercivity (Hc) and saturation field (Hs) of the PMR media stack as a whole. Reduction of intergranular magnetic coupling of the magnetic layers is desirable because it can improve the signal-to-noise ratio (SNR) of the PMR media stack.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a drawing illustrating a perpendicular magnetic recording (PMR) media stack with a CoCrRu-oxide GIIL providing an improved signal-to-noise ratio (SNR) in accordance with an embodiment of the present invention.

FIG. **2** is a drawing illustrating a PMR media stack including a CoCrRu-oxide exchange break layer (EBL) with improved grain segregation, in accordance with an embodiment of the present invention.

FIG. **3** is a plot illustrating a comparison of a PMR media stack including a CoCrRu-oxide GIIL with a PMR media stack including a CoCr-oxide GIIL in terms of coercivity as a function of GIIL thickness in accordance with an embodiment of the present invention.

FIG. **4** is a plot illustrating a comparison of SNR-2T versus magnetic write width (MWW) of PMR media stacks respectively including a CoCr-oxide GIIL and a CoCrRu-oxide GIIL in accordance with an embodiment of the present invention.

FIG. **5** is a plot illustrating a comparison of SNR-1T versus MWW of PMR media stacks respectively including a CoCr-oxide GIIL and a CoCrRu-oxide GIIL in accordance with an embodiment of the present invention.

FIG. **6** is a plot illustrating a comparison of reverse overwrite (OW2) versus MWW between a PMR media stack with a CoCr-oxide GIIL and a PMR media stack with a CoCrRu-oxide GIIL in accordance with an embodiment of the present invention.

FIG. **7** is a plot illustrating a comparison of on-track weighted sum SNR (wsSNR_init) versus adjacent-track wsSNR (wsSNR_final) between a PMR media stack with a CoCr-oxide GIIL and a PMR media stack with a CoCrRu-oxide GIIL in accordance with an embodiment of the present invention.

FIG. **8** is a plot illustrating a comparison of wsSNR_init versus MWW between a PMR media stack with a CoCr-oxide EBL and a PMR media stack with a CoCrRu-oxide EBL in accordance with an embodiment of the present invention.

FIG. **9** is a plot illustrating a comparison of wsSNR_final versus MWW of a media stack with a CoCr-oxide EBL and a PMR media stack with a CoCrRu-oxide EBL in accordance with an embodiment of the present invention.

FIG. **10** is a plot illustrating a comparison of saturation field versus coercivity between a PMR media stack with a CoCr-oxide EBL and a PMR media stack with a CoCrRu-oxide EBL in accordance with an embodiment of the present invention.

FIG. **11** is a plot illustrating a comparison of OW2 versus MWW of a PMR media stack with a CoCr-oxide EBL and a PMR media stack with a CoCrRu-oxide EBL in accordance with an embodiment of the present invention.

FIG. **12** is a conceptual drawing illustrating a hard disk drive including a PMR media stack in accordance with an embodiment of the present invention.

FIG. **13** is a flow chart illustrating a method of fabricating a perpendicular magnetic recording media stack with a CoCrRu-oxide GIIL in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

Reduction of intergranular magnetic coupling of the magnetic layers is a key challenge to improving the signal-to-noise ratio (SNR) for perpendicular magnetic recording (PMR) media. In various aspects of the present invention, a PMR media stack of an exchange coupled composite media (ECC) with improved SNR and a method of making the same are provided.

A perpendicular magnetic recording (PMR) media stack of an ECC generally includes a number of soft magnetic underlayers (SUL), intermediate underlayers (IL), and a number of magnetic layers. To achieve higher areal density for PMR media, it is generally desirable to improve the SNR and writeability of the PMR media. For SNR improvement, it is desirable that the grains of magnetic layer have small grain size, narrow size distribution, and also are well decoupled magnetically. On the other hand, it is desirable that magnetic grain of the magnetic layer has suitably high magnetic anisotropy (Ku) to maintain thermal stability. The magnetic layer may include a CoPtX-oxide alloy (e.g., where X is Cr, Ru, or B, and the oxide is TiO_2, SiO_2, Cr_2O_3, B_2O_3, etc.). Using a CoPtX-oxide alloy, high Ku can be achieved by reducing non-magnetic elements such as Cr, Ru, or oxide; but in doing so magnetic coupling of magnetic grains also increases, which causes undesirable SNR. One solution to improve SNR of PMR media is to use a non-magnetic CoCr-oxide grain isolation initiation layer (GIIL) to overcome or reduce the magnetic coupling of high Ku magnetic layers. The CoCr-oxide GIIL is generally positioned below a magnetic layer of a PMR media stack and provides well-segregated grains with thick oxide grain boundaries. Therefore, PMR media may include the CoCr-oxide GIIL to control and improve segregation of magnetic grains because high Ku materials generally have strong intergranular coupling between magnetic grains.

In various aspects of the present disclosure, a CoCrRu-oxide GIIL may be used to replace the CoCr-oxide GIIL in the PMR media stack. The CoCrRu-oxide GIIL may effectively improve grain segregation of a magnetic layer, increase coercivity (Hc), and also substantially reduce noise of the magnetic media including the CoCrRu-oxide GIIL. In other aspects, the CoCrRu-oxide can also be used in an exchange break layer (EBL) because the CoCrRu-oxide has desirable exchange breaking property as well as segregation enhancement property.

In various aspects of the present disclosure, a novel GIIL may include a CoCrRu-oxide alloy (e.g., where the oxide is TiO_2 at about 10 to 25 atomic percent and the Ru is at about 10 to 40 atomic percent). The presence of Ru in the GIIL can cause the Co to be substantially non-magnetic, and therefore Co may be used as a nonmagnetic intermediate layer if the amount of element (Ru) is more than magnetic transition composition. In one embodiment, the element Ru is completely solid soluble in a Co matrix, and is a strong hexagonal-closed-packed (HCP) phase stabilizer. In the CoCr-oxide GIIL, however, Cr easily can make second phase beyond a certain point because Cr is a body-centered-cubic (BCC) phase stabilizer.

FIG. **1** is a drawing illustrating a PMR media stack **100** with a CoCrRu-oxide GIIL providing an improved signal-to-noise ratio (SNR) in accordance with an aspect of the present disclosure. The segregation enhancement provided by the CoCrRu-oxide GIIL translates to higher coercivity (Hc) and improved on-track weighted sum SNR (wsSNR_init) and adjacent-track wsSNR (wsSNR_final) performance of the PMR media stack **100**. The PMR media stack **100** includes a substrate **102** (e.g., Al—Mg or glass), an antiferromagnetic coupled soft magnetic underlayer (AFC-SUL) **104**, a seed layer **106** (e.g., a NiWAlFe seed layer), dual Ru intermediate layers (ILs) **108**, a CoCrRu-oxide GIIL **110** (e.g., the oxide is TiO_2 at about 10 to 25 atomic percent, and the Ru is about 10 to 40 atomic percent), a number of magnetic layers **112** (e.g., Mag1, Mag2, and Mag3), a capping layer (**114**), and a carbon overcoat (COC) **116**. The magnetic layers **112** are separated by a number of EBLs (**118**). In various embodiments, the magnetic layers may include a CoPtX-oxide alloy, wherein X is selected from the group consisting of Cr, Ru, and B, and the oxide is selected from the group consisting of TiO_2, SiO_2, Cr_2O_3, and B_2O_3. A number of exemplary materials are presented herein. However, in other embodiments, other suitable materials may also be used, including, for example, materials known in the art.

In one embodiment, a PMR media stack may be an exchange coupled composite medium. In one embodiment, a magnetic layer may include a number of magnetic layers (e.g., magnetic layers **112**), and an EBL may include a number of EBLs (e.g., EBLs **118**). The magnetic layers and the EBLs may be alternately arranged. In one embodiment, the EBL may include a CoCrRu-oxide. In one embodiment, the GIIL may include a material selected from the group consisting of a CoCrRu-oxide and a CoCr-oxide. In one embodiment, the EBL may include a number of EBLs, and two of the EBLs may include different materials. In one embodiment, the EBL may include TiO_2 at about 10 to 25 atomic percent and Ru at about 10 to 40 atomic percent.

In the PMR media stack **100**, Co has a hexagonal close packed (HCP) structure while Ru also has a HCP structure with bigger atom diameter. The Ru doping in the GIIL can form Co—Cr—Ru substitution solid solution with larger lattice constants. Therefore, the CoCrRu-oxide GIIL may play a role as a buffer layer to minimize or reduce stress induced by lattice constant mismatch because the atomic size of Ru is bigger than that of Co and Cr, which is closer to that of the Ru IL. Therefore, the lattice mismatch may be controlled and reduced by the amount of Ru in the CoCrRu-oxide GIIL.

In FIG. **1**, the magnetic layers **112** (e.g., Mag1, Mag2, and Mag3) are separated by a number of EBLs **118**. The EBLs **118** help to improve the write-ability of the PMR media stack **100** during the recording process by reducing coercivity (Hc) and saturation field (Hs) of the media stack substantially. The EBL **118** may include a Co—Ru or Co—Cr-oxide alloy. There is a Ku gradient from the Mag1 magnetic layer toward the Mag3 magnetic layer, and the Mag1 magnetic layer has the highest Ku. Because the magnetic layers **112** Mag1 to Mag3 have high Ku and are magnetically coupled, segregation still is important. The EBL **118** may include a CoCr-oxide alloy that serves as a segregation helper as well as an EBL.

FIG. **2** is a drawing illustrating a PMR media stack **200** including an EBL containing a CoCrRu-oxide to improve grain segregation, in accordance with an aspect of the disclosure. The PMR media stack **200** includes, starting from a base or bottom layer, a substrate **202** (e.g., Al—Mg or glass), an antiferromagnetic coupled soft magnetic underlayer (AFC-SUL) **204**, a seed layer **206** (e.g., a NiWAlFe seed layer), dual Ru intermediate layers (ILs) **208**, a CoCrRu-oxide GIIL **210** (e.g., the oxide is TiO_2 at about 10 to 25 atomic percent and the Ru is about 10 to 40 atomic percent), a number of magnetic layers **212** (e.g., Mag1, Mag2, and Mag3), a capping layer (**214**), and a carbon overcoat (COC) **216**. The magnetic layers **212** are separated by a number of EBLs **218** and **219**. The EBLs **218** include a CoCrRu-oxide, and the EBL **219** may be a different material than that of the EBLs **218**. For example, the EBL **219** may include CoRu or other suitable materials known in the art. A number of exemplary materials are presented herein. However, in other embodiments, other suitable materials may also be used, including, for example, materials known in the art.

FIG. **3** is a plot illustrating a comparison of a PMR media stack including a CoCrRu-oxide GIIL (e.g., GIIL **110**) with a PMR media stack including a CoCr-oxide GIIL in terms of coercivity (Hc) as a function of GIIL thickness (nm). For this comparison, both media stacks include a single magnetic layer (e.g., Mag1 in FIG. **1**) of 7 nm and the same IL to compare segregation effect. In FIG. **3**, the horizontal axis corresponds to the GIIL thickness (nm), and the vertical axis corresponds to the coercivity (Oe). The curve **300** of the CoCr-oxide GIIL and the curve **302** of the CoCrRu-oxide GIIL both show similar Hc trends. For each GIIL, its Hc initially increases with thickness until it reaches a maximum Hc **304**. This initial Hc increase is due to improved segregation with the help of the GIIL. Beyond the thickness for the maximum Hc **304**, Hc starts to decrease for both GIILs. The Hc drop can be explained that the segregation effect saturates at the maximum Hc, and subgrains begin to form in the magnetic layer. The difference in Hc between the CoCr-oxide GIIL and the CoCrRu-oxide GIIL is shown in FIG. **3**. The maximum Hc is about 300 to 400 Oe higher for the CoCrRu-oxide GIIL than that of the CoCr-oxide GIIL because CoCrRu may provide better segregation effect to the magnetic layers grown above.

FIG. **4** is a plot illustrating a comparison of SNR-2T versus magnetic write width (MWW) of PMR media stacks respectively including a CoCr-oxide GIIL and a CoCrRu-oxide

GIIL (e.g., GIIL **110** or **210**). FIG. **5** is a plot illustrating a comparison of SNR-1T versus MWW of PMR media stacks respectively including a CoCr-oxide GIIL and a CoCrRu-oxide GIIL (e.g., GIIL **110** or **210**). Improved grain segregation of magnetic layers may be shown by examining high frequency SNR because better grain segregation improves high frequency SNRs at 2T and 1T frequencies, where 1T is the period for the highest frequency of the magnetic media stacks.

In FIG. **4**, the horizontal axis corresponds to MWW in micro-inch, and the vertical axis corresponds to SNR-T2. In FIG. **5**, the horizontal axis corresponds to MWW in micro-inch, and the vertical axis corresponds to SNR-T1. In both FIGS. **4** and **5**, the data corresponding to the CoCrRu-oxide GIIL is denoted by the square symbol **400**, and the data corresponding to the CoCr-oxide oxide GIIL is denoted by the diamond symbol **402**. As shown in FIGS. **4** and **5**, the media stack with the CoCrRu-oxide GIIL layer improves its SNR-2T by about 0.2 dB and SNR-1T by about 0.4 dB for a given MWW (e.g., between about 2.65 and 2.70 micro-inch).

FIG. **6** is a plot illustrating a comparison of reverse overwrite (OW2) versus magnetic write width (MWW) between a PMR media stack with a CoCr-oxide GIIL and a PMR media stack with a CoCrRu-oxide GIIL (e.g., GIIL **110** or **210**). In FIG. **6**, the horizontal axis corresponds to the MWW (micro-inch), and the vertical axis corresponds to OW2 (dB). The data corresponding to the CoCr-oxide GIIL is denoted by the square symbol **500**, and the data corresponding to the CoCrRu-oxide GIIL is denoted by the diamond symbol **502**. Generally, a more magnetically decoupled PMR media stack has poor OW2 relatively. FIG. **6**, however, shows that the PMR media stack with the CoCrRu-oxide GIIL has comparable OW2 to that of the PMR media stack with the CoCr-oxide GIIL.

FIG. **7** is a plot illustrating a comparison of on-track weighted sum SNR (wsSNR_init) versus adjacent-track wsSNR (wsSNR_final) between a PMR media stack with a CoCr-oxide GIIL and a PMR media stack with a CoCrRu-oxide GIIL (e.g., GIIL **110** or **210**). In FIG. **7**, the horizontal axis corresponds to wsSNR_init (dB), and the vertical axis corresponds to wsSNR_final (dB). As shown in FIG. **7**, the PMR media stack with the CoCrRu-oxide GIIL shows improvement on wsSNR_init as well as wsSNR_final by about 0.2 dB.

FIG. **8** is a plot illustrating a comparison of wsSNR_init versus MWW between a PMR media stack with a CoCr-oxide EBL and a PMR media stack with a CoCrRu-oxide EBL (e.g., EBL **218**). FIG. **9** is a plot illustrating a comparison of wsSNR_final versus MWW of a media stack with a CoCr-oxide EBL and a PMR media stack with a CoCrRu-oxide EBL (e.g., EBL **218**). In both FIGS. **8** and **9**, the data corresponding to the CoCrRu-oxide EBL is denoted by the diamond symbol **600**, and the data corresponding to the CoCr-oxide EBL is denoted by the square symbol **602**. In both FIGS. **8** and **9**, the horizontal axis corresponds to the MWW (micro-inch). In FIG. **8**, the vertical axis corresponds to wsSNR_init (dB). In FIG. **9**, the vertical axis corresponds to wsSNR_final (dB). The media stack with a CoCrRu-oxide EBL shows both wsSNR_init and wsSNR_final improvement by about 0.1 dB as compared to the CoCr-oxide EBL.

FIG. **10** is a plot illustrating a comparison of Hs versus Hc between a PMR media stack with a CoCr-oxide EBL and a PMR media stack with a CoCrRu-oxide EBL (e.g., EBL **218**). FIG. **11** is a plot illustrating a comparison of OW2 versus MWW of a PMR media stack with a CoCr-oxide EBL and a PMR media stack with a CoCrRu-oxide EBL (e.g., EBL **218**). In both FIGS. **10** and **11**, the data corresponding to the CoCrRu-oxide EBL is denoted by the diamond symbol **700**, and the data corresponding to the CoCr-oxide EBL is denoted by the squire symbol **702**. In FIG. **10**, the horizontal axis corresponds to Hc (Oe), and the vertical axis corresponds to Hs (Oe). In FIG. **11**, the horizontal axis corresponds to MWW (micro-inch), and the vertical axis corresponds to OW2 (dB). As shown in FIG. **10**, Hs is higher for the PMR media stack with a CoCrRu-oxide EBL for a given Hc because this media is more decoupled magnetically. Due to increased Hs, as shown in FIG. **11**, OW2 is affected (increased) by about 0.5 dB for the PMR media stack with a CoCrRu-oxide EBL.

FIG. **12** is a conceptual drawing illustrating a hard disk drive **800** including a PMR media stack in accordance with an embodiment of the present invention. The disk drive **900** may include a disk **902** to store data. The disk **902** may include a PMR media stack similar to the PMR media stack **200** or **300**. The disk **902** resides on a spindle assembly **904** that is mounted to a drive housing **906**. Data may be stored along tracks in a magnetic recording layer of the disk **902**. The disk drive **900** also includes a spindle motor (not shown) that rotates a spindle assembly **904** and, thereby, the disk **902** to position a read/write head **912** at a particular location along a desired disk track. The position of the read/write head **912** relative to the disk **902** may be controlled by a position control circuitry **914**. Components of the disk drive **900** that are generally known in the art and not necessary for understanding the present invention, are omitted for clarity.

FIG. **13** is a flow chart illustrating a method **1000** of fabricating a perpendicular magnetic recording media stack in accordance with an embodiment of the present invention. In step **1002**, a soft underlayer (e.g., underlayer **104** or **204**) is formed on a substrate (e.g., substrate **102** or **202**). In step **1004**, an interlayer (e.g., interlayer **108** or **208**) is formed and positioned on the soft underlayer. In step **1006**, a grain isolation initiation layer (e.g., GIIL **110** or **210**) is formed and positioned on the interlayer. In one aspect, the GIIL includes a CoCrRu-oxide. In step **1008**, a magnetic layer (e.g., Mag1 **112** or **212**) is formed and positioned on the GIIL. In step **1008**, an exchange break layer (e.g., EBL **118** or **218**) is formed and positioned on the magnetic layer.

In several embodiments, the deposition of layers can be performed using a variety of deposition sub-processes, including, but not limited to physical vapor deposition (PVD), sputter deposition and ion beam deposition, and chemical vapor deposition (CVD) including plasma enhanced chemical vapor deposition (PECVD), low pressure chemical vapor deposition (LPCVD) and atomic layer chemical vapor deposition (ALCVD). In other embodiments, other suitable deposition techniques known in the art may also be used.

It shall be appreciated by those skilled in the art in view of the present disclosure that although various exemplary fabrication methods are discussed herein with reference to magnetic recording media, disks or wafers containing magnetic heads, the methods, with or without some modifications, may be used for fabricating other types of recording disks, for example, optical recording disks such as a compact disc (CD) and a digital-versatile-disk (DVD), or magneto-optical recording disks, or ferroelectric data storage devices.

While the above description contains many specific embodiments of the invention, these should not be construed as limitations on the scope of the invention, but rather as examples of specific embodiments thereof. Accordingly, the scope of the invention should be determined not by the embodiments illustrated, but by the appended claims and their equivalents.

The various features and processes described above may be used independently of one another, or may be combined in various ways. All possible combinations and sub-combinations are intended to fall within the scope of this disclosure. In addition, certain method, event, state or process blocks may be omitted in some implementations. The methods and processes described herein are also not limited to any particular sequence, and the blocks or states relating thereto can be performed in other sequences that are appropriate. For example, described tasks or events may be performed in an order other than that specifically disclosed, or multiple may be combined in a single block or state. The example tasks or events may be performed in serial, in parallel, or in some other suitable manner. Tasks or events may be added to or removed from the disclosed example embodiments. The example systems and components described herein may be configured differently than described. For example, elements may be added to, removed from, or rearranged compared to the disclosed example embodiments.

What is claimed is:

1. A perpendicular magnetic recording (PMR) media stack comprising:
- a substrate;
- a soft underlayer on the substrate;
- an interlayer positioned on the soft underlayer;
- a non-magnetic grain isolation initiation layer (GIIL) positioned on the interlayer, the GIIL comprising a CoCrRu-oxide;
- a magnetic layer positioned on the GIIL; and
- an exchange break layer (EBL) positioned on the magnetic layer,
- wherein the magnetic layer comprises a plurality of magnetic layers, and the EBL comprises a plurality of EBLs, the magnetic layers and the EBLs being alternately arranged, and
- wherein each of the plurality of EBLs is configured to prevent a magnetic exchange coupling between a first layer above and a second layer below the each of the plurality of EBLs.

2. The PMR media stack of claim **1**, wherein the GIIL comprises TiO2 at about 10 to 25 atomic percent and Ru at about 10 to 40 atomic percent.

3. The PMR media stack of claim **1**, wherein the magnetic layer comprises a CoPtX-oxide alloy, wherein X is selected from the group consisting of Cr, Ru, and B, and the oxide is selected from the group consisting of TiO2, SiO2, Cr2O3, and B2O3.

4. The PMR media stack of claim **1**, wherein the interlayer comprises Ru.

5. The PMR media stack of claim **1**, wherein the substrate comprises a material selected from the group consisting of Al—Mg and glass.

6. The PMR media stack of claim **1**, wherein the soft underlayer comprises an antiferromagnetic coupled soft magnetic underlayer.

7. A perpendicular magnetic recording (PMR) media stack comprising:
- a substrate;
- a soft underlayer on the substrate;
- an interlayer positioned on the soft underlayer;
- a non-magnetic grain isolation initiation layer (GIIL) positioned on the interlayer, the GIIL comprising a CoCrRu-oxide;
- a magnetic layer positioned on the GIIL; and
- an exchange break layer (EBL) positioned on the magnetic layer,
- wherein the magnetic layer comprises a plurality of magnetic layers, and the EBL comprises a plurality of EBLs, the magnetic layers and the EBLs being alternately arranged,
- wherein a first EBL and a second EBL of the plurality of EBLs, comprise different materials, and
- wherein the first EBL comprises a CoCrRu-oxide, and the second EBL comprises a CoCr-oxide.

8. The PMR media stack of claim **7**, wherein the first EBL comprises TiO2 at about 10 to 25 atomic percent and Ru at about 10 to 40 atomic percent.

9. A hard disk drive comprising the PMR media stack of claim **1**.

10. A method of fabricating a perpendicular magnetic recording (PMR) media stack, the method comprising:
- forming a soft underlayer on a substrate;
- forming an interlayer positioned on the soft underlayer;
- forming a non-magnetic grain isolation initiation layer (GIIL) positioned on the interlayer, the GIIL comprising a CoCrRu-oxide;
- forming a magnetic layer positioned on the GIIL; and
- forming an exchange break layer (EBL) positioned on the magnetic layer,
- wherein the magnetic layer comprises a plurality of magnetic layers, and the EBL comprises a plurality of EBLs, the magnetic layers and the EBLs being alternately arranged, and
- wherein each of the plurality of EBLs is configured to prevent a magnetic exchange coupling between a first layer above and a second layer below the each of the plurality of EBLs.

11. The method of claim **10**, wherein the GIIL comprises TiO2 at about 10 to 25 atomic percent and Ru at about 10 to 40 atomic percent.

12. The method of claim **10**, wherein the magnetic layer comprises a CoPtX-oxide alloy, wherein X is selected from the group consisting of Cr, Ru, and B, and the oxide is selected from the group consisting of TiO2, SiO2, Cr2O3, and B2O3.

13. The method of claim **10**, wherein the interlayer comprises Ru.

14. The method of claim **10**, wherein the substrate comprises a material selected from the group consisting of Al—Mg and glass.

15. The method of claim **10**, wherein the soft underlayer comprises an antiferromagnetic coupled soft magnetic underlayer.

16. A method of fabricating a perpendicular magnetic recording (PMR) media stack, the method comprising:
- forming a soft underlayer on a substrate;
- forming an interlayer positioned on the soft underlayer;
- forming a non-magnetic grain isolation initiation layer (GIIL) positioned on the interlayer, the GIIL comprising a CoCrRu-oxide;
- forming a magnetic layer positioned on the GIIL; and
- forming an exchange break layer (EBL) positioned on the magnetic layer,
- wherein forming the magnetic layer comprises forming a plurality of magnetic layers; and
- wherein forming the first EBL comprises forming a plurality of EBLs, the magnetic layers and the EBLs being alternately arranged,
- wherein a first EBL and a second EBL of the plurality of EBLs, comprise different materials, and
- wherein the first EBL comprises a CoCrRu-oxide, and the second EBL comprises a CoCr-oxide.

17. The method of claim **16**, wherein the first EBL comprises TiO_2 at about 10 to 25 atomic percent and Ru at about 10 to 40 atomic percent.

18. The method of claim **10**, wherein the GIIL comprising the CoCrRu-oxide comprises Ru at about 10 to 40 atomic percent.

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